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DEVELOPMENT AND IMPLEMENTATION OF EFFICIENT AND LOW COST MULTIPURPOSE AGRICULTURAL EQUIPMENT FOR TEFF PLANTATIONS FOR SMALL SCALE FARMERS IN RURAL COMMUNITIES

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ABSTRACT

This paper present design, development and implementation of electric powered, multipurpose small scale 'teff' row plantation three wheeled locomotive machine that can sow a hectare with 5 kg of 'teff' in 20 cm spaced rows. A detail design and analysis is made for all components of the row planter either manually or using commercial software like ANSYS and CAD model is made up using Solidworks. After completion of design and analysis, all custom parts are fabricated and standard parts are bought and assembled. On completion of all fabrication and assembly process, field test is made to evaluate successful running of the electric three wheeled vehicle and examine row planting parameter as per our design. The degree of variation in seed distribution is found to be 11.15 %which is far satisfactory compared to traditional broadcast planting. And, missing and multiple indexes are observed to be zero and there was no visible damage caused to seed grains on field test.

KEYWORDS: Ethiopia, 'Teff', Row Plantation, Electric Three Wheeled Vehicle & Seed Distribution Variation

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Original Article

1. INTRODUCTION

'Teff' (*Eragrostis'teff')* is the most well-known and extensively consumed cereal in Ethiopia among the other agricultural products, and its importance is beyond being staple food as it is connected to the socio-cultural heritage of the society. *'Teff'* productivity was 1.4 ton per hectare by 2013, which is low when compared to other cereals such as maize (3.1 ton per hectare), rice (2.8 ton per hectare) and wheat (2.1 ton per hectare) [1]. This can be explained by numerous restraining reasons as traditional sowing technology, insufficient usage of modern inputs such as inorganic fertilizer and better-quality seed, post-harvest and processing losses which is worsened combined with problems inherent to *'teff'* botany and others. Among these factors, it is argued that the traditional way of planting seed is a main constraint to increased *'teff'* productivity [2].

This work is initiated by our daily experience of farmers' way of planting and reality of low *'teff'* yield in Ethiopia because of lack of mechanized and simple row planter. Farmers broadcast *'teff'* seed traditionally, with high seed rate of 25 to 50 kg per hectare [3] which decreases yield because, uneven and dense scattering of seed increases competition between seedlings for water, light, and nutrients, and makes weeding more difficult. Reducing the seed rate to 2.5–3.0 kg per hectare by row planting reduces competition between plants and allows for optimal tillering, simplify land management and weeding [4]. But row planting is tough due to increased labor requirement, compared to the traditional broadcast planting. Considering this increased requirement for labor, this study is undertaken to develop and implement mechanized electric battery driven *'teff'* row planter which allow

more precise adjustment for the seed rate and a uniform seed distribution.

2. LITERATURE REVIEW

2.1 Previous Works on *'Teff'* Row Planter

Tesfaye Gonite and Hiluf Reda, sited [5] have designed and developed human operated row planter in Debrebirhan University that apply *'teff'* and fertilizer in row simultaneously.

Figure 1: 'Teff' and Fertilizer Applier by Tesfaye Gonite and Hiluf Reda.

IDEO, a group of designers from Palo Alto, have tried to develop *'teff'* row planter (figure 2a) by adapting the existing large seed metering unit to *'teff'* size [6]. Test is done on field with a human pulling the planter and it is found to be cumbersome due to the muddy soil. And they suggest further study for improvement. Hawassa University staff have developed the *'teff'* row planter shown in figure 2b [5].

Figure 2: *'Teff' R*ow Planter by (a) IDEO (b) Hawassa University.

3. METHODOLOGY

3.1 Data Collection

In order to design the seed metering mechanism and calculate the component dimensions, load and power requirement, facts and statistics on physical properties of *'teff'* and fertilizer and scientifically recommended agronomic parameters was necessary. These data are found from official yearly reports published by Ethiopia Ministry of Agriculture (MoA), Ethiopian Agricultural Transformation Agency (ATA), Ethiopian Central Statistical Agency (CSA), Ethiopian Strategic Support Program and scientific research outcomes done by Ethiopian Development and Research Institute (EDRI), UNDP and other published journals. And, we made a repeated field visit to get more familiar with existing practice and examine nature of the soil.

Different literature give a little varied amount of seeding rate per hectare depending on the fertility of soil. Berhe sited [2] wrote a seeding rate of 2.5- 3 kg per hectare reduces competition between seedlings and allows for optimal tillering. MoA [7] suggest a seed rate of 5 kg per hectare for good *'teff'* productivity.

Wider spacing have positive influence on the performance of individual plants as there is ample space for seedlings and help them draw enough nutrients and solar radiation which in turn produces more effective tiller and longer panicle than dense spacing. However, increasing row spacing beyond specified amount is not always beneficial to yield [8]. According to ATA [3], the optimum row spacing gap is given to be 20 cm.

Again ATA [3] have suggested a seeding depth of 2-3 cm for *'teff'*. A firm seedbed should be prepared for *'teff'* through moderate soil compaction to prevent the soil surface from drying quickly which causes seed dehydration, and enhance germination [9]

Though farmers have varied practice due to several reasons, the recommended rate of fertilizer application in *'teff'* production is 100kg of DAP/ha and 100kg of urea/ha as set by the MoA.

3.2 Multipurpose Row Planter Layout and Working Principle

The operating principle is explained here in reference to the assembly pictorial drawing shown in figure 3. The driver start, stop, control speed and direction with the help of a geared BLDC motor (not shown), high frequency PWM speed controller and steering arm (30). The motor is supplied with lead-acid vehicle battery (45). The motor shaft having a pinion at its tip will mesh with electric differential (11) and its speed and rotation direction are control controlled by a multifunction PWM controller. The seed and fertilizer metering system is assembled in box (25) that is partitioned into two, one for *'teff'* seed and the other for fertilizer. There is a shaft (22) passing though each partition of the box. In the *'teff'* seed box there is a metering disc (23) keyed to the aforementioned shaft that is rotated by the vehicle wheel (14) through a chain drive (28). A very small cell made up of metal sheet having calculated volume is welded on the periphery of the disc in such way that, it can be able to displace a recommend amount of seed at a time. The rotational speed of the seed metering disc is synchronized to the speed of the wheel of the vehicle through a chain, so that the seed flow-rate will be proportional with the vehicle speed. In the fertilizer metering box partition, the same shaft is spiked to small cylindrical bucket (43) in order to displace recommended amount of fertilizer at a time. The volume of each bucket is calculated to carry the suggested amount of fertilizer. The displaced seed and fertilizer is conveyed to the prepared furrow with help of short PVC pipe (41 and 21) which is attached at the back of the furrow maker (40) at the other end.

In order to prepare a level seedbed before furrow making, a set of chained heavy rolled steel metal (seedbed maker) (46) that is towed by the vehicle front section of chassis is dragged over the soil. Then, a furrow is ploughed with slightly forward slanted right angled steel after which the seed is drilled immediately with the help of PVC pipe extending from the seed metering box. The furrow maker is hinged on the chassis (1) so that it can be tilted up when no use.

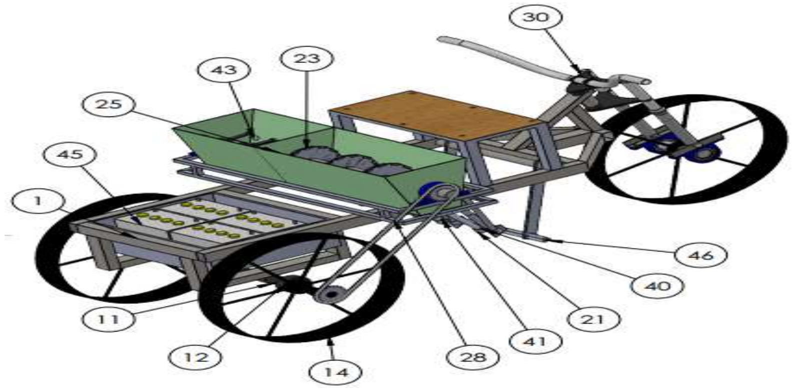

Figure 3: Assembly 3D Drawing of the Row Planter.

3.3 Seed Metering Unit Design

Considering the sandy and less fertile nature of Aksum area soil, we take the higher seeding rate (5 kg per hectare) suggested by MoA with 20 cm row spacing. Considering square land *100 m X 100 m* there will be 500 rows per hectare or the planter have to travel 50,000 m to cover one hectare.

The diameter of our vehicle wheel is $d_w = 64\ cm$, hence the circumference will be $c_w = \pi d_w = 2\ m$. So, we need 25,000 rotations to plant 1 hectare of land. But with the tread width of the three wheeled vehicle we can plant four rows in one pass and hence we need 6250 rotations to plant 1 hectare.

To plant 1 hectare with 5 kg of '*teff*' seed, we have to sow $8 \times 10^{-4}\ kg$ per rotation. And, in each row we have to sow $2 \times 10^{-4}\ kg$ per rotation as we plant four rows at a time. The seed metering disc has a diameter of $20\ cm$ and will provide 12 equidistant circumferentially scattered cell on its periphery for spooning and delivering seed. As a result, each cell should displace $1.67 \times 10^{-5}\ kg$ per rotation. According to Zewdu and Solomon (2007) bulk density of '*teff*' at moisture content of 5.6 % is 600 kg/m^3, and hence each cell should have a volume of $28\ mm^3$. Still being pessimist and taking spooning and releasing inaccuracy of 30 %, we took a cell volume of $37\ mm^3$.

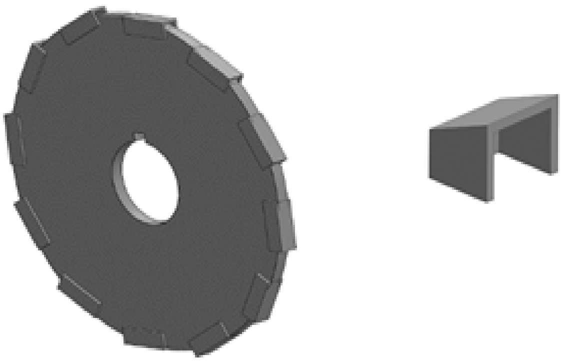

Figure 4: Metering Disc and Cell

3.4 Tractive Force Analysis and Motor Selection

3.4.1 Specifications

Wheel rim diameter, d_w is $64\ cm$ and total mass, $m_t = 200\ kg$ including chassis mass with the seeder box, $m_c = 80\ kg$, seed and fertilizer mass, $m_s = 10\ kg$, driver (more than average mass of Ethiopian adult), $m_d = 80\ kg$ battery, $m_b = 7.5 \times 4 = 30\ kg$

The tractive force must be greater than or equal to the resistive forces (aerodynamic resistance, F_a, rolling resistance, F_{rr}, gradient resistance, F_g) in order to maintain a sustainable motion. In addition, a force required to accelerate the vehicle from stop or to overcome inertial resistance during unsteady operation, inertia (acceleration) force, F_{accel} should be included. Aerodynamic resistance (pressure and drag) can be neglected as travelling speed and area exposed to direct pressure and drag are very small.

3.4.2 Rolling Resistance

The wheel having a thickness of 10 cm is made of structural steel (ASTM A36/A3M) and hence the rolling resistance force

is calculated considering a friction between structural steel (ASTM A36/A3M) and muddy farm soil in which the vehicle normally work. The following equation can be used [10];

$$F_{rr} = C_{rr} \times W_t \tag{1}$$

Where surface friction coefficient C_{rr} for a metal wheel on a mud having medium thickness is 0.09 [11] and W_t is total weight. Hence, $F_{rr} = 180\ N$

3.4.3 Gradient Resistance, F_g

The amount of force necessary to move a vehicle up a slope or grade is calculated considering the maximum angle or grade, θ_{max} the vehicle is expected to climb in Aksum University area land mark in normal operation. It is estimated to be 5^0. Hence,

$$F_g = W_t \sin\theta_{max} = 517.64\ N \tag{2}$$

3.4.4 Acceleration Force, F_{acc}

F_{acc} can be calculated using Newton's 2nd law of motion, $F_{acc} = m_t a$. We took acceleration time of 10 sec to attain working speed of $20\ {}^{km}/_{hr}$. Hence, $F_{acc} = 112\ N$

3.4.5 Inertial Resistance Due to Rotating Components, F_d

In addition to above resistance forces, we have also inertial resistance due to rotation of seed metering discs, fertilizer metering buckets and shaft itself which should be considered. It can be estimated as follows;

$$F_d = \frac{4m_d {v_d}^2}{r_d} = 30.63\ N \tag{3}$$

Where m_d, v_d, r_d are mass, velocity and radius of seed metering disc respectively.

3.4.6 Total Tractive Resistance, TTR

The total tractive resistance will be the sum all above resistance forces.

$$TTR = F_{acc} + F_g + F_{rr} = 840.27\ N \tag{4}$$

3.4.7 Tractive Effort Required, TE

Tractive effort at wheels required to maintain sustained motion of the vehicle can be calculated as follows.

$$TE = \frac{TTR \times R_w}{\eta_t N_t} = 33.61\ Nm \tag{5}$$

Where R_w is radius of wheel and η_t, N_t are efficiency and transmission ratio of electric differential.

3.4.8 Tractive Power Required, P_t

$$P_t = \frac{2\pi \times N \times TE}{60} = 588.16\ W \tag{6}$$

Where N is rpm of the wheel

Considering discrepancies like friction losses in the chain and bearing, driving irregularities and the driver may take someone else with him/her for short ride, we decide to select 1000 W motor. Searching on manufacturer's catalogue, we have picked a geared BLDC motor of 1000 W, 48 V with PWM speed controller.

3.5 Battery Selection

In order to select the battery, we need to calculate our energy requirement with $48\,V$ in the system. The maximum operating current of the BLDC motor can be found as,

$$I = \frac{P}{V} = 12.25\,A \tag{7}$$

Let's say the working hour per day will be *6 hours*, and hence, Amp-hours per day will be, $20.8 \times 6 \times 1.1 = 80.87\,Ah/day$, assuming a total loss of $10\,\%$. Hence, the energy requirement will be $= 80.87 \times 48 = 3881.86\,Wh/day$. This energy will be supplied by four $12\,V, 35\,Ah$ batteries.

3.6 Chassis Frame Design

The frame is made in the form of ladder like structure having a series of cross members and delta like extension at the front to suit steering column and front wheel mounting. It is made from $60 \times 40\,mm$ structural steel, ASTM A36/A36M RHS and reinforced with angle bars where necessary. It has a wheel Base (b) of 4800 mm and width (t) of 2250 mm.

Linear static structural analysis is performed to identify critical regions using commercial design software package, ANSYS 16.0 and based on the results obtained design modification has been done.

3.7 Meshing

The structure is meshed using multi-zone mesh control and most of the elements are made hexahedral (figure 5a). After performing mesh sensitivity analysis with 100 % relevance, an element size of 5 mm is found to be optimum and the elements are 19211in number with 80869 nodes. The relevance center is made fine and smoothing is kept medium with slow transition. While meshing, element quality parameters like aspect ratio, skewness, jacobian, and warpage are all duly watched.

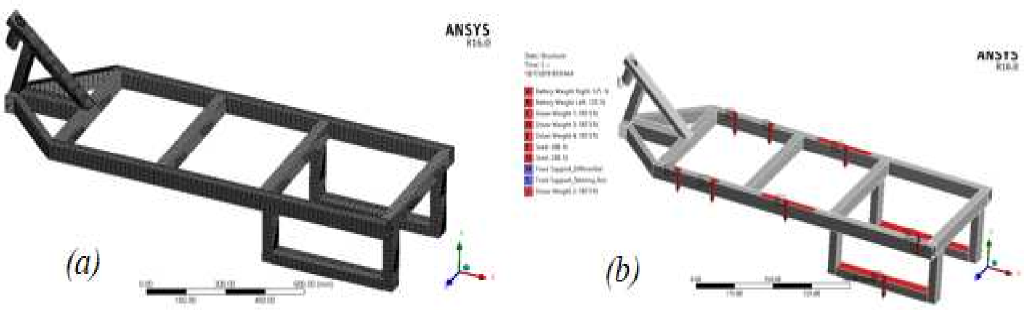

Figure 4: (a) Mesh (b) Boundary Condition.

3.8 Boundary Condition

By considering an average Ethiopian adult, a driver weight of 800 N is taken. The seed hopper with seed weighs 400 N and all four batteries have a total weight of 250 N including the battery box. All of these forces are applied vertically in the

negative *y*-direction on their respective locations as shown in figure 5b. The chassis frame is constrained with fixed support at the front and rear wheel by arresting all degrees of freedom.

3.9 Static Structural Analysis Solution

Von Moses stress, total deformation and reaction forces at the supports are calculated using ANSYS mechanical solver. The maximum deformation is found to be 0.42 mm close front end of the chassis frame which is fairly tolerable.

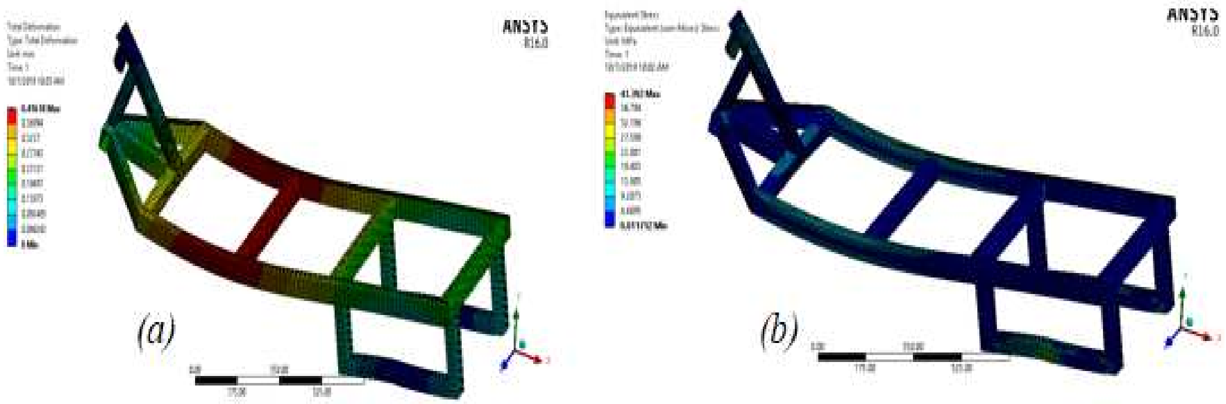

Figure 5: (a) Total Deformation (b) Principal Stress.

The maximum Von Moses stress is found to be 41.39 MPa around the top tip of steering column and differential clamping location. This value of stress is far less than the material ASTM A36/A36M tensile yield strength which is 250 MPa and hence, our design is proved to be safe.

3.10 Modal Analysis

Due to uneven operation on farm, the vehicle is prone to vibration and hence, it is very important to perform vibration analysis to insure rigidity and avoid resonance. Modal analysis is made to determine natural frequencies and corresponding vibration mode shapes of the structure.

Table 1

Mode	Frequency (Hz)	Maximum Deformation (mm)
1	68.322	15.1
2	71.248	10.48
3	109.33	11.09
4	161.83	13.52
5	202.55	10.76
6	210.77	11.72

Road excitation frequency is lower than each of the above frequencies. And hence, none of the frequency of above mode shapes match the excitation frequency of the vehicle and hence, there is no resonance.

3.11 Brief Fabrication Process

The vehicle frame is made from $60 \times 40 \times 2\,mm$ RHS by with arc welding using 6013 electrode and the electric differential having a BLDC motor is attached to it using U-shaped clamp. The hub of each half drive shaft is bolted to the steel wheel with the help of a nug nut.

Figure 6: Differential Fitted to Frame.

Speed control throttle is screwed to the steering arm key as well as MCB switch are all located near to the front. The seeding hopper made by bending sheet metal is bolted to a separate bracket and the seed metering disc shaft is passed through it with the help of bearings. The furrow maker is made from tubular steel with a right angled steel welded at the end for row ploughing and it is hinged to the frame under the seed hopper.

Figure 7: Final Assembly of Three Wheeled Locomotive Row Planter.

3.12 Field Test

The test is performed by running the three wheeled vehicle at speed of approximately $20\ km/hr$ and by adding $2\ kg$ of '*teff*' and hard core sand to emulate the fertilizer in the seeder and recording a video and pictures at important points. Various row planting quality measures such as seed distribution characteristics, degree of variation, missing index, multiple index and seed damage are investigated.

Figure 8: Seeder with Seed and Fertilizer.

4. RESULTS AND DISCUSSIONS

4.1 Three Wheeled Vehicle Operation

The vehicle successfully runs and accelerate carrying load of the driver and the seed. It has climbed the grade of hilly (we have assumed a grade of 15^0 in tractive force analysis) test area environment as expected. The power transmission to the seed metering unit through chain was smooth and the front shock absorber response to farm bump and the running all bearings were all adequate.

4.2 Seed Distribution Uniformity

It is difficult to see seed distribution on farm, because, '*teff*' grain is white which is similar in color with sandy Aksum area soil. And though, it was cumbersome to identify the seed from the soil on camera, we have marked the three seed rows in figure 10. Seed distribution characteristics is measured by degree of variation i.e. the degree of variation of spacing which is given by equation

$$\%_{var} = \frac{std\ dev}{s_{th}} \tag{8}$$

Figure 10: Row Planted 'Teff' Grain Image.

Table 2

Measurement Instance	Measured Spacing Between Two Closest Seed of Adjacent Rows, $S_i\ (cm)$	Measurement Instance	Measured Spacing Between Two Closest Seed of Adjacent Rows, $S_i\ (cm)$
1	16.5	9	16
2	18	10	17
3	17.6	11	16.7
4	16.1	12	15
5	15	13	21
6	14	14	17.5
7	22	15	17
8	20	9	16

So, the degree of variation will be 11.15 % which is far better compared to traditional broadcast sowing. This variation is caused due to various reasons specially spill-over of seed and fertilizer when the vehicle travel on big bump and slight splash of seeds before reaching the seeder box opening due to centrifugal force at high speed. This is shown by screen shot image from a recorded video in figure. In addition to this, seed distribution is also caused by wind though it have minor effect as the seed feeding tube is very close to ground.

Figure 11: Seed and Fertilizer Spill-Over and Splash.

And, missing and multiple index are both zero which implies fair row wise even seed scattering. Further, there was no visible damage caused to seed grains on field test which is again crucial as injured seed is compromised to germinate.

5. CONCLUSIONS

A small scale electric powered multipurpose '*teff*' row planting machine is designed, fabricated and implemented in this research work. After making detail design and analysis, and fabricating of all components of the row planter, it assembled ant tested on field farm to evaluate successful running of the electric three wheeled vehicle and examine row planting parameters. The degree of variation in seed distribution is found to be *11.15 %* which is far satisfactory compared to traditional broadcast planting. And, there was no missing and multiple index observed and there was no visible damage caused to seed grains on field test. Hence, from these drawn test findings, we have concluded that, an electric three wheeled multipurpose row planter that can plant a hectare with 5 kg of '*teff*' in 20 cm spaced rows is developed and implemented successfully in research work.

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2. International Journal on Enhancing surface finishing optimization of CNC Machining parameters on AA2024 using response surface methodology(IJETS-2349-3968)